Female Pelvic Floor Anatomy: The Pelvic Floor, Supporting Structures, and Pelvic Organs

Sender Herschorn, MD, FRCSC
Division of Urology, Sunnybrook and Women's College Health Sciences Centre, Toronto, Ontario

The development of novel, less invasive therapies for stress urinary incontinence in women requires a thorough knowledge of the relationship between the pathophysiology of incontinence and anatomy. This article provides a review of the anatomy of the pelvic floor and lower urinary tract. Also discussed is the hammock hypothesis, which describes urethral support within the pelvis and provides an explanation of the continence mechanism.
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Key words: Pelvis • Pelvic diaphragm • Endopelvic fascia • Urogenital diaphragm • Urethra • Continence

The effective management of stress urinary incontinence (SUI) requires knowledge of the pathophysiologic mechanisms behind the disorder. Key to identifying these mechanisms and providing proper treatment to women with SUI is an understanding of the anatomy and function of the female pelvic floor and its supporting structures.

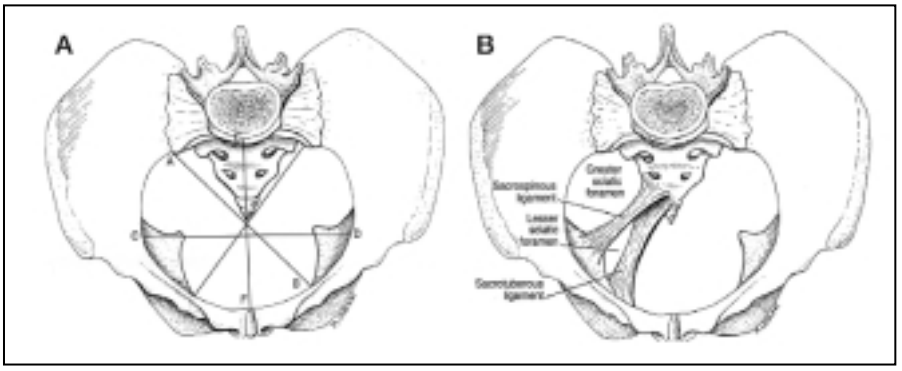


Figure 1. (A) *The diameters of the female minor pelvis (superior aperture): A, sacroiliac joint; B, iliopubic eminence; C and D, middle of pelvic brim; E, sacral promontory; F, pubic symphysis.* **(B)** *The female pelvis from above: The sacrospinous ligament extends from the ischial spines to the lateral margins of the sacrum and coccyx anteriorly to the sacrotuberous ligament, which extends from the ischial tuberosity to the coccyx. The sciatic foramina are above and below the sacrospinous ligament and anterior to the sacrotuberous ligament. Reprinted, with permission, from Herschorn S, Carr LK. In:* Campbell's Urology. *2002:1092-1139.*[36]

Bony Scaffolding

The maintenance of continence and prevention of pelvic organ prolapse rely on the support mechanisms of the pelvic floor. The bony pelvis consists of the 2 innominate bones, or hip bones, which are fused to the sacrum posteriorly and to each other anteriorly at the pubic symphysis. Each innominate bone is composed of the ilium, ischium, and pubis, which are connected by cartilage in youth but fused in the adult.[1] The pelvis has 2 basins: the major (or greater) pelvis and the minor (or lesser) pelvis. The abdominal viscera occupy the major pelvis; the minor pelvis is the narrower continuation of the major pelvis inferiorly. The inferior pelvic outlet is closed by the pelvic floor.

The female pelvis (Figure 1A) has a wider diameter and a more circular shape than that of the male. The wider inlet facilitates head engagement and parturition. The wider outlet predisposes to subsequent pelvic floor weakness. Numerous projections and contours provide attachment sites for ligaments, muscles, and fascial layers. Of note is the thin and triangular sacrospinous ligament (Figure 1B), which extends from the ischial spines to the lateral margins of the sacrum and coccyx anteriorly to the sacrotuberous ligament. Its anterior surface is muscular and constitutes the coccygeus; the ligament is often regarded as the degenerate part of the muscle.[1] The greater and lesser sciatic foramina are above and below the ligament.

Muscular Supports of the Pelvic Floor

Pelvic Diaphragm

The levator ani and coccygeus muscles that are attached to the inner surface of the minor pelvis form the muscular floor of the pelvis. With their corresponding muscles from the opposite side, they form the pelvic diaphragm (Figure 2). The levator ani is composed of 2 major muscles from medial to lateral: the pubococcygeus and iliococcygeus muscles.

The bulkier medial portion of the levator ani is the pubococcygeus muscle that arises from the back of the body of the pubis and anterior portion of the arcus tendineus. The arcus tendineus of the levator ani is a dense connective tissue structure that runs from the pubic ramus to the ischial spine and courses along the surface of the obturator internus muscle. The muscle passes back almost horizontally to behind the rectum. The inner border forms the margin of the levator (urogenital) hiatus, through which passes the urethra, vagina, and anorectum.

Various muscle subdivisions have been assigned to the medial portions of the pubococcygeus to reflect the attachments of the muscle to the urethra, vagina, anus, and rectum.[2] These portions are referred to by some investigators as the pubourethralis, pubovaginalis, puboanalis, and puborectalis—or collectively as the puboviscerali, because of their association and attachment to the midline viscera.[3]

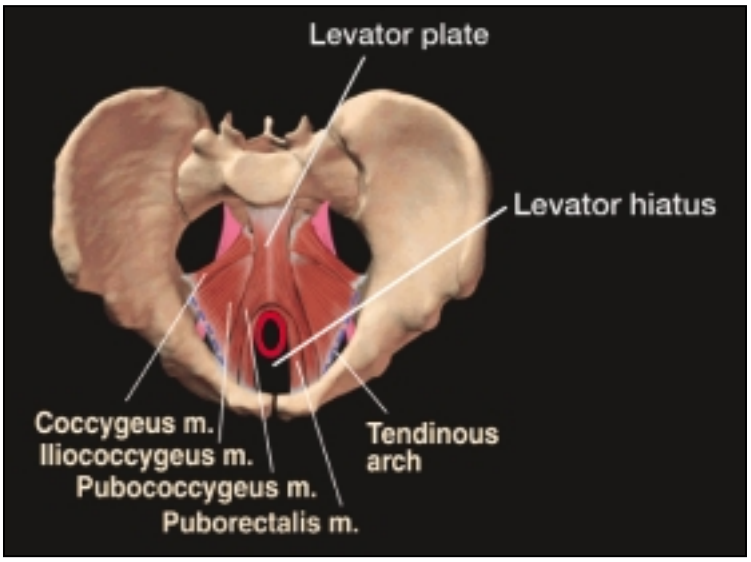


Figure 2. *Pelvic diaphragm.*

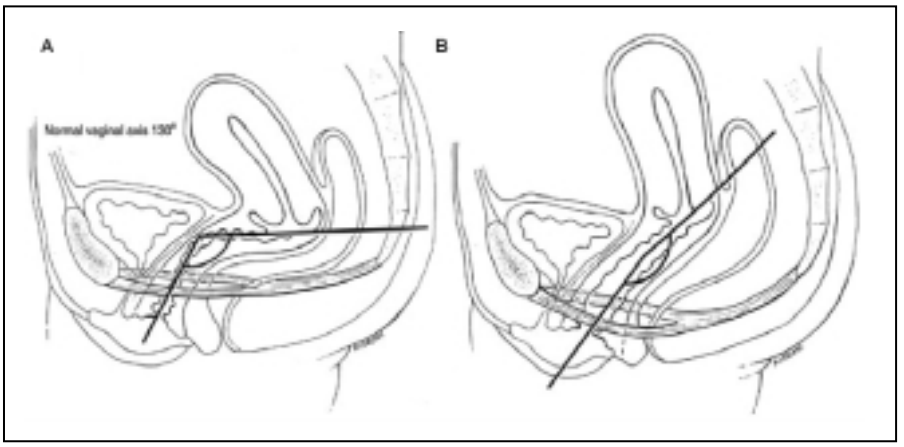


Figure 3. *Pelvic floor support (midsagittal section of the pelvis):* **(A)** *normal tone in the levator ani with acute anorectal angle and horizontal levator plate; note the normal vaginal axis.* **(B)** *With loss of tone in the levator ani, there is change in the vaginal axis, sagging of the levator plate, and enlargement of the urogenital hiatus. Reprinted, with permission, from Herschorn S, Carr LK. In:* Campbell's Urology. *2002:1092-1139.*[16]

The urethral portion forms part of the periurethral musculature, and the vaginal and anorectal portions insert into the vaginal walls, perineal body, and external anal sphincter muscle.[4] The puborectalis portion passes behind the rectum and fuses with its counterpart from the opposite side to form a sling behind the anorectum. Other more posterior parts of the pubococcygeus attach to the coccyx.

The thin lateral part of the levator ani is the iliococcygeus muscle, which arises from the arcus tendineus of the levator ani to the ischial spine. Posteriorly it attaches to the last 2 segments of the coccyx. The fibers from both sides also fuse to form a raphe and contribute to the anococcygeal ligament. This median raphe between the anus and the coccyx is called the levator plate and is the shelf on which the pelvic organs rest. It is formed by the fusion of the iliococcygeus and the posterior fibers of the pubococcygeus muscles. When the body is in a standing position, the levator plate is horizontal and supports the rectum and upper two thirds of vagina above it. Weakness of the levator ani may loosen the sling behind the anorectum and cause the levator plate to sag.[5] This opens the urogenital hiatus and predisposes to pelvic organ prolapse (Figure 3). Women with prolapse have been shown to have an enlarged urogenital hiatus on clinical examination.[6]

The coccygeus muscle that extends from the ischial spine to the coccyx and lower sacrum forms the posterior part of the pelvic diaphragm. It sits on the anterior surface of the sacrospinous ligament. Three-dimensional magnetic resonance imaging (MRI) of the pelvic diaphragm (Figure 4) shows its peripheral attachments and demonstrates the urogenital hiatus.[7]

Direct innervation of the levator ani muscle on its cranial surface is primarily from the third and fourth sacral nerve roots via the pudendal nerve.[8] The puborectalis may derive some if its innervation from a pudendal branch on the caudal side.[2] Regarding the type of the striated muscle, it has been reported that the majority of the muscle fibers in the levator ani are slow-twitch fibers that maintain constant tone (type I),[9] with an increased density of fast-twitch (type II) fibers distributed in the periurethral and perianal areas.[10,11] This suggests that the normal levator ani maintains tone in the upright position to support the pelvic viscera. Furthermore, voluntary squeezing of the puborectalis may increase the tone to counter increased intra-abdominal pressure.

Urogenital Diaphragm (Perineal Membrane)

Another musculofascial structure, the urogenital diaphragm, is present over the anterior pelvic outlet below the pelvic diaphragm. However, there is controversy over whether this structure contains a transverse sheet of

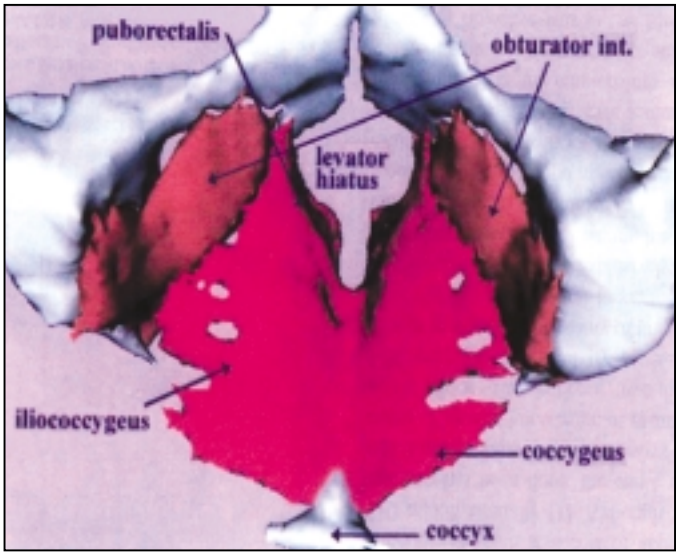


Figure 4. *Three-dimensional reconstructed magnetic resonance image of a 28-year-old healthy woman showing pelvic floor muscles and bones. The keyhole shape indicates normal separation of the vagina and rectum and intact perineal body. Reprinted from Fielding JR et al.* AJR Am J Roentgenol. *2000; 174:657-660.*[7] *Reprinted with permission from the* American Journal of Roentgenology.

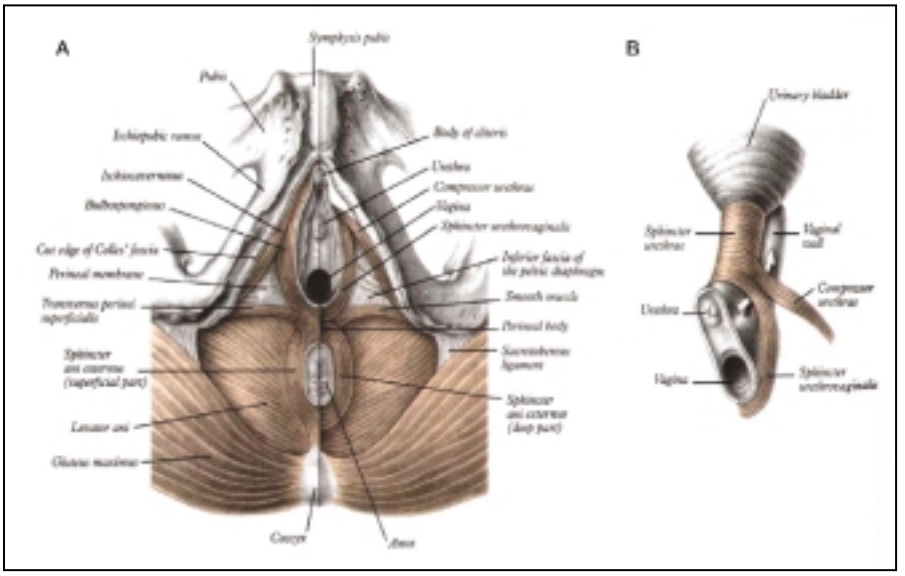


Figure 5. *Muscles of the perineum:* (A) *On the subject's right side, the membranous layer of the superficial fascia has been removed (note the cut edge). On the subject's left side, the symphysis pubis, pubis, part of the ischiopubic ramus, superficial perineal muscles, and inferior fascia of the urogenital diaphragm have been removed to show the deep perineal muscles.* (B) *Deep perineal muscles are continuous with the sphincter urethrae. Reprinted, with permission, from Salmons S. In:* Gray's Anatomy. *1995:737-900.*[4]

muscle extending across the pubic arch (deep transverse perinei muscle) sandwiched between superior and inferior fascia[12] or 3 contiguous striated muscles (compressor urethrae, sphincter urethrae, and urethrovaginalis) and an inferior fascial layer called the perineal membrane (Figure 5).[4,13,14] Despite the controversy, MRI scans clearly depict the structure.[2,12]

The more superficial ischiocavernosus and bulbocavernosus muscles, as well as the thin slips of the superficial transverse perinei,[14] complete the inferior aspect of the urogenital diaphragm. The structure bridges the gap between the inferior pubic rami bilaterally and the perineal body. It closes the urogenital (levator) hiatus; supports and has a sphincter-like effect at the distal vagina; and, because it is attached to periurethral striated muscles, contributes to continence. It also provides structural support for the distal urethra. The posterior triangle around the anus does not have a corresponding diaphragm or membrane. The ischiorectal fossae are the spaces lateral to the anus below the pelvic diaphragm.

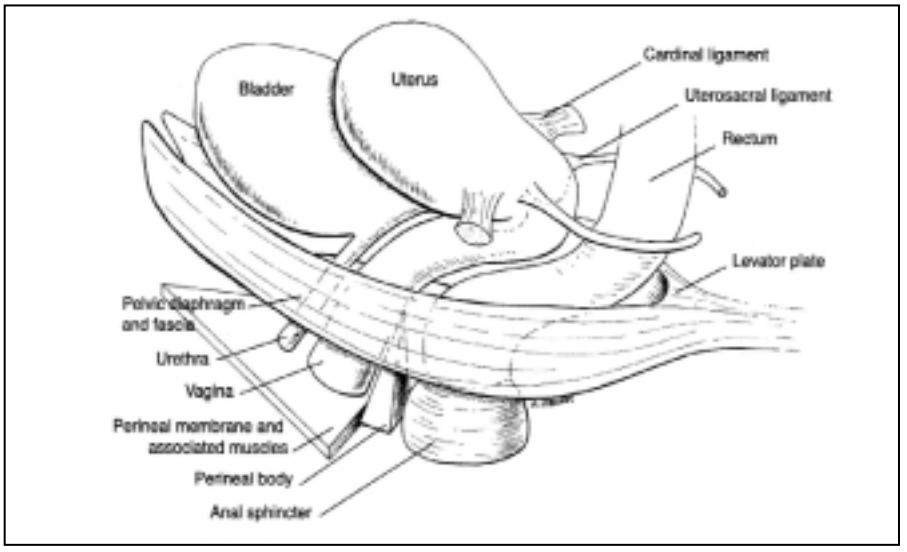
Perineal Body

The perineal body is a pyramidal fibromuscular structure in the midline between the anus and vagina with the rectovaginal septum at its cephalad apex.[4] Below this, muscles and their fascia converge and interlace through the structure. Attached to the perineal body are the rectum, vaginal slips from the pubococcygeus, perineal muscles, and the anal sphincter; it also contains smooth muscle, elastic fibers, and nerve endings. During childbirth, the perineal body distends and then recoils.[12] It is an important part of the pelvic floor; just above it are the vagina and the uterus. Acquired weakness of the perineal body gives rise to elongation and predisposes to defects such as rectocele and enterocele.[14,15] Figure 6 demonstrates the pelvic organs with the 2 major levels of muscular support: the upper muscular structure, with the pelvic diaphragm, and the lower muscular structure, with the perineal membrane anteriorly and anal sphincter posteriorly.

Endopelvic Fascia and Connective Tissue Supports

The bladder and urethra and the vagina and uterus are attached to the

Figure 6. *The 2 major muscular supporting structures: the upper, with the pelvic diaphragm, and the lower, with the perineal membrane (urogenital diaphragm) anteriorly and anal sphincter posteriorly. Reprinted, with permission, from Herschorn S, Carr LK. In:* Campbell's Urology. *2002:1092-1139.*[36]



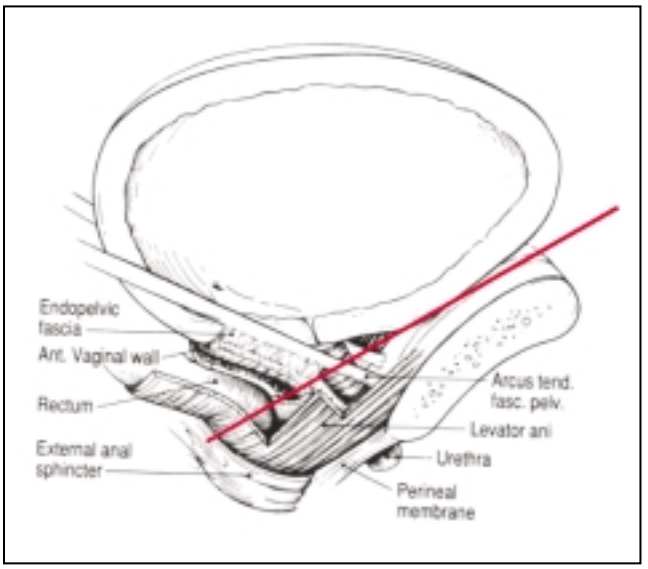


Figure 7. *The hammock hypothesis: the anterior vaginal wall with its attachment to the arcus tendineus of the pelvic fascia forms a hammock under the urethra and bladder neck. Reprinted, with permission, from DeLancey JOL.* Am J Obstet Gynecol. *1996;175:311-319.*[37]

pelvic walls by a system of connective tissue that has been called the endopelvic fascia. This structure lies immediately beneath the peritoneum and is one continuous unit with various thickenings or condensations in specific areas. The endopelvic fascia is continuous with the visceral fascia, which provides a capsule containing the organs and allows displacements and changes in volume. The distinct regions of this structure are given individual names, specifically ligaments and fascia, with variable internal structure. Endopelvic fascia and ligaments are a mesh-like group of collagen fibers interlaced with elastin, smooth muscle cells, fibroblasts, and vascular structures. The structures that attach the uterus to the pelvic wall, the cardinal ligaments, derive strength from the supportive collagen forming the walls of arteries and veins. Other structures, such as the pelvic sidewall attachment of the endopelvic fascia (arcus tendineus of the pelvic fascia), are predominantly fibrous collagen.[16]

Anterior Supports

There is agreement among investigators that the connective tissue supports of the urethra, bladder, and vagina extend to the arcus tendineus of the pelvic fascia on the pelvic diaphragm.[2,12,17,18] There is also agreement that a "hammock" of anterior vaginal wall tissue, bridging the gap medially in the urogenital hiatus, supports the vesical neck and urethra.[17,19] There is controversy, however, focusing on the connective tissue structures that are associated with this hammock.

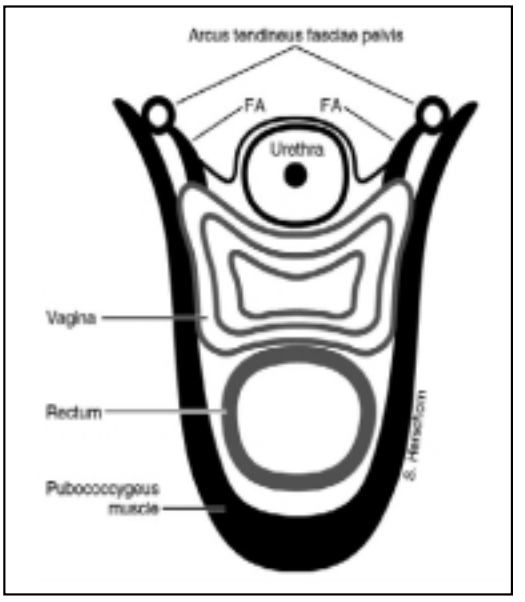


Figure 8. *Cross section of urethral supports below the bladder neck: The urethra is supported by a hammock of anterior vaginal wall suspended to the levators (pubococcygeus muscles) and the fascial attachments (FA) to the tendinous arch of the pelvic fascia. In essence, it is a "double hammock." Reprinted, with permission, from Herschorn S, Carr LK. In:* Campbell's Urology. *2002:1092-1139.*[36]

The pubourethral ligaments are connective tissue structures that extend from the urethra to the pubic bone. Various authors have described them as structures responsible for supporting the urethra and keeping the vesical neck closed.[20-23] However, other authors have described connective tissue between the proximal urethra (and vesical neck) and the pubis as containing smooth muscle[24] and cholinergic nerves[25] that make the structures more suited to vesical neck opening during micturition than to urethral support. Because there is an attachment of the lower third of the urethra to the pubis, it is postulated that there are 2 separate structures—one for support at the mid- or distal urethra and one near the bladder neck that may open it during voiding. The distal support has been described as connective tissue that joins the vaginal wall and periurethral tissue to the arcus tendineus of the pelvic fascia and the levator muscles.[24] Since the arcus tendineus inserts into the pubic bone, these are the ligaments that are palpable during a retropubic dissection. These ligaments

are important for urethral support.[23]

There is controversy regarding the amount of supportive tissue or fascia in the anterior vaginal wall. Although the wall is composed of mucosa, muscularis, and adventitia and abuts a similar arrangement in both the urethra and bladder, various authors have attributed to it a vaginal fascial layer. Weber and Walters[18] cited many articles on both sides of the controversy and reported no specific fascial layer, whereas DeLancey[17] demonstrated a fascial layer suburethrally on the anterior vaginal wall. With or without the suburethral fascial layer, the anterior vaginal wall supports the urethra by its lateral attachment to the levators (pubococcygeus) and to the endopelvic fascia from the arcus tendineus of the pelvic fascia (Figures 7 and 8). In essence, it is a double hammock. Paradoxically, the more advanced the prolapse, the more thickened and hypertrophied is the vaginal submucosal layer.[18]

Urethropelvic ligaments from the suburethral fascia at the bladder neck and proximal urethra to the levators and arcus tendineus have been described and demonstrated on MRI scans.[12] The existence of these ligaments as separate entities apart from the hammock of tissue supporting the proximal urethra has been disputed.[26,27]

At the level of the bladder base, there is little actual endopelvic fascia between the bladder and vaginal muscularis. Here, the support comes from the lateral attachment of the vagina to the arcus tendineus of the pelvic fascia.[17] The pubocervical fascia has been described as extending from the symphysis along the anterior vaginal wall to blend with the fascia that surrounds the cervix. It is continuous laterally with the pubococcygeus and also suspended to the arcus tendineus of the pelvic fascia. Its existence as a separate and discernable entity is also in dispute.[18]

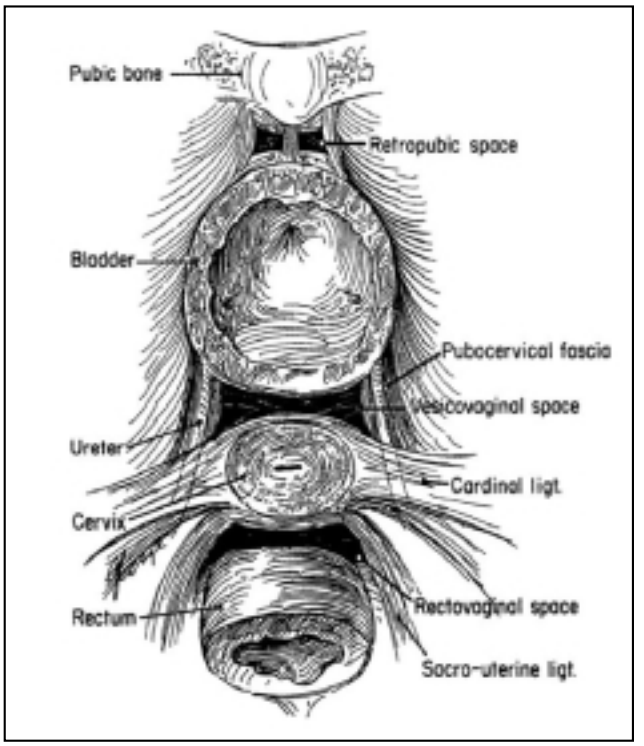


Figure 9. *The cardinal and uterosacral ligaments provide support to the cervix and indirectly to the bladder base. The retropubic, vesicovaginal, and rectovaginal spaces are seen at the level of the cervix. Reprinted, with permission, from Raz S et al. In:* Campbell's Urology. *1998:1059-1094.*[30]

Middle Supports

The paracolpium and parametrium are the connective tissues surrounding the vagina and the uterus, respectively. In the midvagina, the paracolpium fuses with the pelvic wall and fascia laterally.[28] The cardinal ligaments (also called the transverse cervical ligaments of Mackenrodt) extend from the lateral margins of the cervix and upper vagina to the lateral pelvic walls. They originate over a large area from the region of the greater sciatic foramen over the piriformis muscles, from the pelvic bones in the region of the sacroiliac joint, and from the lateral sacrum. They are condensations of the lowermost parts of the broad ligaments. Laterally, the cardinal ligaments are continuous with the connective tissue surrounding the hypogastric vessels. Medially, they are continuous with the paracolpium and parametrium as well as the connective tissue in the anterior vaginal wall, the so-called pubocervical fascia.

The uterosacral ligaments are attached to the cervix and upper vaginal fornices posterolaterally. Posteriorly, they attach to the presacral fascia in front of the sacroiliac joint. The connective tissue of the uterosacral ligaments is continuous with that of the cardinals around the cervix. The cardinal and uterosacral ligaments hold the uterus and upper vagina in their proper place over the levator plate.[29] This supportive structure is depicted in Figure 9. According to Raz and colleagues,[30] the cardinals and uterosacrals are not directly important for continence but do play a role in the support of the bladder base in the surgical correction of large cystoceles.

Posterior Supports

The posterior vaginal wall, below the cardinals, is supported from the sides by the paracolpium, which is attached to the endopelvic fascia (referred to as rectovaginal fascia in this area) and pelvic diaphragm. The anterior and posterior fascial layers unite along the

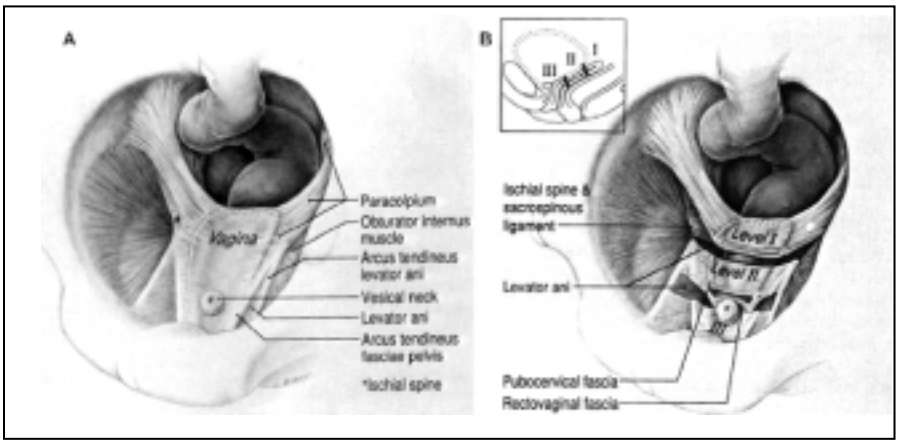


Figure 10. (A) *Vagina and supportive structures drawn from dissection of a 56-year-old cadaver after hysterectomy: The bladder has been removed above the vesical neck. Paracolpium extends along the lateral wall of vagina.* **(B)** *In level I, paracolpium suspends vagina from the lateral pelvic walls. In level II, the vagina is attached to arcus tendineus of pelvic fascia and superior fascia of levator ani muscles. Reprinted, with permission, from DeLancey JOL.* Am J Obstet Gynecol. *1992;166:1717-1728.*[28]

sides of the vagina (Figure 10). According to DeLancey,[28] the rectovaginal fascia is found mostly at the sides and is extremely thin in the midline of the vaginal wall. However, a posterior rectovaginal septum, consisting of fibromuscular elastic tissue, extending from the peritoneal reflection to the perineal body has been described.[21] During fetal life, the peritoneal cavity extends to the cranial part of the perineal body, but it becomes obliterated in early life. Its fused layers (Denonvillier's fascia) probably become part of the rectovaginal septum adherent to the undersurface of the posterior vaginal wall. This fascia forms the anterior margin of another potential space, the rectovaginal space. The rectovaginal septum, if intact and normal, permits independent mobility of the rectal and vaginal walls.

In the distal vagina, 2 cm to 3 cm above the hymeneal ring, the vaginal wall is directly attached to surrounding structures without any intervening paracolpium. Anteriorly, the vagina fuses with the urethra and the connective tissue of the perineal membrane and muscles (urogenital diaphragm). Laterally, it blends with the levator ani muscles and, posteriorly, it fuses with the perineal body. The rectovaginal fascia is thickest in this region,[31] and the vagina in this area has no mobility separate from its adjacent structures.[28]

The fascial supports for the rectum, the lateral rectal ligaments, extend from the posterolateral pelvic side wall (level with the third sacral vertebra) to the rectum and surround the middle rectal arteries. Additional prerectal and pararectal fascial elements are frequently described.[30]

Urethra

The urethra is a complex tubular structure extending below the bladder to the external meatus (Figure 11). It has distinct muscular elements associated both within and without to permit its functioning for storage (continence) and voiding.

The smooth muscle of the urethra is contiguous with that of the trigone and detrusor.[32] It has a prominent inner longitudinal and a thin outer circular layer. The layers lie inside the outer striated urogenital sphincter muscle and are present throughout the upper four fifths of the urethra. The configuration of the circular muscle implies a role in constricting the lumen, and the longitudinal muscle may aid in shortening the urethra during voiding.[33]

The outer layer of the urethra is

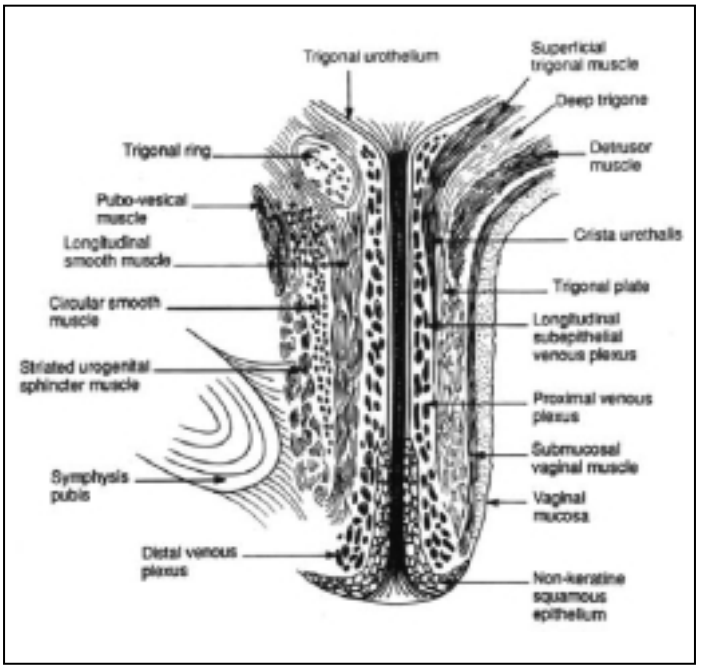


Figure 11. *Urethral anatomy: the urethra has distinct muscular elements associated both within and without to permit its functioning for storage and voiding. Reprinted, with permission, from Strohbehn K, DeLancey JOL.* Oper Tech Gynecol Surg. *1997;2:5-16.*[38]

formed by the muscle of the striated urogenital sphincter that is found in the middle three fifths of the length. In its upper two thirds, the sphincter-like fibers are circular. In the distal part, the fibers exit the urethra and surround the vaginal wall as the urethrovaginal sphincter or extend along the inferior pubic rami above the perineal membrane as the compressor urethra.[1] The muscle is composed mainly of slow-twitch fibers, well suited for maintaining constant tone.[10] Voluntary muscle activation can also increase the constriction of the urethra when needed.

The urethral mucosa extends from the bladder transitional epithelium to the external meatus and is primarily nonkeratinizing squamous epithelium. It is derived from the urogenital sinus along with the lower vagina and vestibule. It is hormonally sensitive and undergoes changes with stimulation.[33] The hormonally sensitive submucosal tissue contains a rich and prominent vascular plexus. Several specialized types of arteriovenous anastomoses have been demonstrated, and it is thought that they provide a watertight closure of the mucosal surface with an increase in blood flow that may occur with an increase in pressure on abdominal vessels.[32]

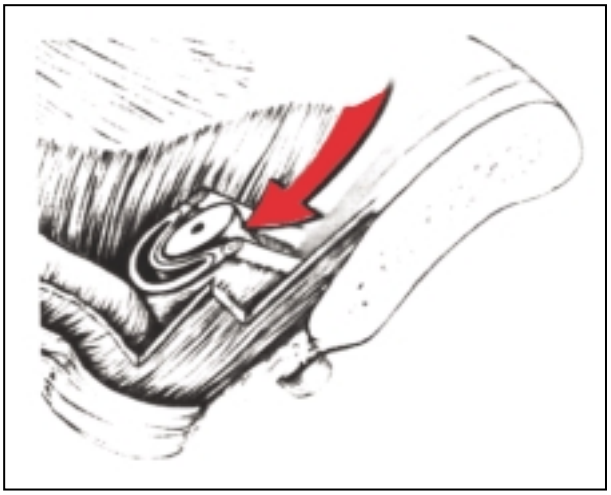


Figure 12. *Lateral view of the pelvic floor with the urethra, vagina, and fascial tissues transected at the level of the vesical neck, drawn from 3-dimensional reconstruction indicating compression of the urethra by downward force (arrow) against the supportive tissues. Reprinted, with permission, from DeLancey JOL.* Am J Obstet Gynecol. *1996; 175:311-319.*[37]

In addition to the muscular and vascular tissue of the urethra, there is a considerable quantity of connective tissue interspersed within the muscle and submucosa. This tissue contains collagen and elastin fibers and is thought to add to urethral closure passively.[33] Lastly, a series of glands are found in the submucosa, mainly along the vaginal surface of the urethra.[34] They are most predominant in the middle and lower third of the urethra.

It is the admixture of the smooth and striated muscle, connective tissue, mucosa, and submucosa that accounts for a functional sphincter.[35] A functional urethral sphincter has intact neural control and provides watertight apposition of the urethral lumen, compression of the wall around the lumen, and a means of compensating for abdominal pressure changes.

Mechanism of Continence

The "hammock hypothesis" (Figure 12) is a readily understood way to explain the continence mechanism. The requirements for continence include a quiescent bladder, functioning musculofascial supports, and a functional urethral sphincter mechanism. The fascial attachments connect the periurethral tissue and anterior vaginal wall to the arcus

Main Points

- The levator plate, the shelf on which the pelvic organs rest, is horizontal when the body is in a standing position and supports the rectum and upper two thirds of the vagina above it. Weakness of the levator ani may loosen the sling behind the anorectum and cause the levator plate to sag, opening the urogenital hiatus and allowing pelvic organ prolapse.
- The urogenital diaphragm closes the levator hiatus, supports and has a sphincter-like effect at the distal vagina, provides structural support for the distal urethra, and contributes to continence in that it is attached to the periurethral striated muscles.
- There is controversy regarding whether the anterior vaginal wall includes a suburethral fascial layer; regardless, the anterior vaginal wall provides support to the urethra by its lateral attachment to the levators and to the endopelvic fascia from the arcus tendineus of the pelvic fascia.
- A combination of smooth and striated muscle, connective tissue, mucosa, and submucosa are necessary for a functional urethral sphincter, which provides watertight apposition of the urethral lumen, compression of the wall around the lumen, and a means of compensating for abdominal pressure changes.
- The "hammock hypothesis" describes support of the urethra by a coordinated action of fascia and muscles, which provides a hammock onto which the urethra is compressed during increases in intra-abdominal pressure.

tendineus at the pelvic sidewall, whereas the muscular attachments connect the periurethral tissue to the medial border of the levator ani.[24] Urethral support is provided by a coordinated action of fascia and muscles acting as an integrated unit under neural control.[33] This musculofascial support provides a hammock onto which the urethra is compressed during increases in intra-abdominal pressure. One can surmise that the urethral sphincter mechanism is operative and adds to the process. Furthermore, failure of one of the support components will not invariably produce stress incontinence, because of the compensatory effect of the other component. This may explain why some women with hypermobility have no incontinence. It may also explain why injectable agents can be used in women with hypermobility: the bulking agent may improve urethral sphincter function.

Conclusions

Increased knowledge of the anatomy of the pelvic floor and lower urinary tract has led to a better understanding of the pathophysiology of incontinence. This, in turn, has led to the development of newer and minimally invasive treatment options for stress incontinence. Although these treatment options are widely applicable, not all patients are candidates or will respond. It is in the setting of the complex patient with incontinence with or without pelvic organ prolapse that the clinician must call on his or her knowledge of anatomy to guide treatment decision making. ■

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